Teaching Creativity in Computer Science

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ABSTRACT
In this paper, we describe how a multidisciplinary undergraduate course in Conducting Robots becomes a venue for fostering creativity and teaching strategies for creativity enhancement. We perform a number of creativity measurements and explain our results in the context of creativity research.

Categories and Subject Descriptors
K.3.2. **[Computers and Education]**: Computer and Information Science Education – Computer science education; J.2. **[Computer Applications]**: Physical Sciences and Engineering – Engineering; J.5. **[Computer Applications]:** Arts and Humanities – Music

General Terms
Algorithms, Design, Human Factors.

Keywords
creativity, multidisciplinary, music, orchestral conducting, robotics

1. INTRODUCTION
A problem that we encounter as computer science educators is the perceived lack of creativity of our subject. Although computers are highly valued in our world, when asked to name some creative activities, people will rarely say computer science. There are many possible reasons for this. One is that creativity tends to be seen as mystified, inspired by a muse, and applicable only to performance in one or more of the arts [13]. The other is that computer scientists, more so than other scientists, are perceived as "geeks" who spend their lives in a cubicle in front of the computer, doing things that nobody else understands.

SIGCSE'13, March 6–9, 2013, Denver, Colorado, USA.

Even our majors often have a hard time seeing the creativity of the subject, especially when constrained by the boundaries of traditional courses. Yet computer science is creative in more than one way: not only can one apply creativity to it, it can also be applied to other fields creatively.

Keeping this reality in mind, we designed and taught an undergraduate seminar whose goal was to engage students – majors and non-majors alike – creatively in computer science. We went one step further and attempted to teach students creativity. In the seminar, undergraduate students majoring in computer science, interactive multimedia, mechanical engineering and music, worked in multidisciplinary teams to develop robotic or animated systems that could conduct an orchestra.

Were we successful? Did our students become more creative? Can creativity be taught and learned? The easy approach to answering these questions would be to measure student creativity at the beginning of the semester, and once again at the end of the semester, and look for a significant increase. Unfortunately our analysis cannot be that simple. Creativity has several different definitions, and, accordingly, several different measures. Many of them are difficult to administer twice. Moreover, the results of different measurements seem to be inconsistent at first.

In this paper we argue that creativity in computer science is different from creativity in the arts. Although some researchers argue that creativity is innate, we show that certain traits of certain types of creativities can be learned, resulting in increased creativity. We present a number of quantitative and qualitative creativity measurements that we performed on the students enrolled in our class, and we explain our results using theories from creativity research. Finally we conclude that our approach was successful, and attractive multidisciplinary settings in general are good venues for teaching students to think and problem solve creatively.

2. DEFINING, MEASURING AND ENHANCING CREATIVITY
Theories about the nature of creativity and how to measure it are still actively debated among researchers. Some theories propose that creativity is the generation of imaginative new ideas [10], involving radical innovations. Other definitions claim that

creativity can be demonstrated by simply integrating existing knowledge in new ways, or require a creative solution to have value or utility [7]. Yet other definitions attempt to reconcile these approaches, such as the one by Plucker et al: Creativity is "the interaction among *aptitude, process, and environment* by which an individual or group produces a *perceptible product* that is both *novel and useful* as defined within a *social context*" [12]. We find that this definition best reflects the field of computer science.

One of the most popular ways to assess creativity is through the Torrance Test of Creative Thinking, which has been refined over the course of several decades [18]. It is a divergent thinking test, which asks participants to produce several responses to a specific prompt (e.g., alternate uses for a shoe, which may include bug killing device, door stop, container etc.) [19]. However, many researchers agree that while divergent thinking is useful, and maybe even necessary in the creative process, as it provides a variety of starting points, it is not sufficient [19].

An alternative is assessment through an inventory of self-reported creative activities and accomplishments [8]. This approach implies that individuals become more creative by participating in creative endeavors.

Another approach is the consensual assessment technique proposed by Amabile [1], which measures the creativity of a product, not an individual. According to her, "a product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated".

We used all three types of measurement in our class setting.

Once we have a definition for creativity and a way to measure it, we can set out to answer our original question: can creativity be taught? Can individuals be made more creative? We set out with the optimistic assumptions of Nickerson: all people of normal intelligence have the potential to be creative to some degree, but few people realize anything close to their potential in this regard. Therefore creativity can be enhanced, although it is not well understood how to do this [11].

3. THE MULTIDISCIPLINARY SETTING

The vehicle for our investigation was a multidisciplinary undergraduate seminar that we developed, in which student teams built non-human systems that conducted our college orchestra. Called "Conducting Robots", this semester-long course has been offered four times so far. Each time the course was cross-listed in the departments of Computer Science, Interactive Multimedia, Mechanical Engineering, and Music, and was taught by a team of four instructors, one from each department (the authors). We worked with an independent evaluator to develop and administer student surveys and interviews. In addition, students were asked to keep a reflection journal. These tools were used to assess creativity and document the creative process.

Since it is a multidisciplinary seminar, open to students with different backgrounds, the structure of the Conducting Robots course is different from that of a traditional course. Students form interdisciplinary teams from the first week and start brainstorming design ideas right away. The semester starts with one or two lectures specific to each discipline, which serve as a refresher to in-major students while providing out of major students with a basic introduction. Topics include robotics, visual music, abstract animation, algorithms, data processing, procedural animation, music conducting, and project management. Homeworks are assigned in each discipline, and students are expected to rely on their in-major teammates for problem solving. After this introductory period, teams spend their time designing and building their systems. The structure of classes changes from the traditional lecture to an informal conversational setting, where teams share progress reports and discuss specific project related problems with the instructors. Depending on the situation, instructors invite guest speakers who can better address some of the issues encountered by the teams.

The final objective of the course is to have students build graphical and/or robotic non-human conductors that can conduct an orchestra. The minimum requirement for each system is to indicate beat patterns, tempo, dynamics and cueing to a human ensemble in real-time.

Throughout the course, students work together in multidisciplinary teams, contributing and developing knowledge from within their own fields, as well as learning fundamentals from the other fields involved. Each time the course was offered so far, at the end of the semester, all teams were able to demonstrate functional systems that performed in a concert with student musicians. Systems were either animations or robots, depending on whether the team had mechanical engineers. Each system fit one of four categories: humanoid robots (like Honda's ASIMO whose conducting performance [9] inspired some of the students), humanoid animations, non-humanoid robots (including devices tailored for individual musicians), and non-humanoid animations (some of them akin to video game interfaces). Some of the prototypes are pictured in Figure 1.

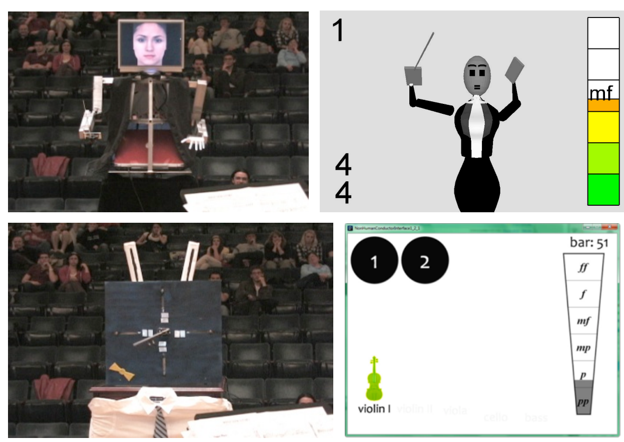

Figure 1. Conducting robot prototypes developed by students. Clockwise from top right: humanoid robot, humanoid animation, non-humanoid animation, and non-humanoid robot

The course presented a number of challenges for students and faculty alike, but all students built working conducting systems at a level that is rare in an undergraduate class setting, and is more characteristic of graduate research. While doing so, they learned to collaborate with other students and apply their knowledge to other fields, as well as communicate cogently about their own disciplines to non-specialists. The collaboration between these fundamentally different fields motivated and inspired our students.

A more detailed description of the course can be found in [14].

4. OUR MEASUREMENTS

4.1 Torrance Test

In an attempt to get a baseline for student creativity, we started each semester by administering the Abbreviated Torrance Test for Adults (ATTA) to the students. This test provides a creativity index, a standardized score that takes into account the raw test score for fluency, originality, elaboration, flexibility and adds extra points for ten different creativity indicators such as sound or movement, resistance to closure, synthesis of two or more figures, abstractness of title, etc. We have found that, in spite of the small number of data points (over the four semesters we taught the class we administered the test to 60 students), the creativity index distribution was very close to the ATTA standardized score distribution. In other words our students scored very similarly to the national sample on which the test was standardized.

In general our students seemed to have average creativity. We found no significant difference between the creativity index of males and females, between classes, or between majors. The only significant difference was between music majors and engineering majors, with the music majors scoring higher, enforcing yet again the popular view of music being a more creative field than engineering.

4.2 Self-reported Creativity

We also asked the students to rate their own creativity on a scale from 1 (least creative) to 10 (most creative). This self-ranking was based on students' creative activities and accomplishments, following the approach in [8]. Interestingly, the only correlation that we found between the self-ranking and the ATTA creativity index was at the two ends of the spectrum, for the most and the least creative students.

As discussed above, the definition of creativity is still a matter of debate among researchers and laypeople alike. When we asked students to rate their own creativity, we also asked them to define it. A vast majority replied that creativity was "thinking outside the box", and the ability to create something new. Only two or three students each semester mentioned using other people's ideas as part of the creative process. By the end of the semester, when students were asked to rate how the diversity of their team influenced the creativity of their solution, it was the exact opposite: only two or three students per semester did not give credit to other people's ideas.

At the end of the semester most students agreed that the multidisciplinary team environment increased the creativity of their project. They also reported that they were able to come up with creative solutions that they would not have found while working alone. This aspect was consistent, regardless of major. On a scale from 1 to 10 where 1 meant "not much at all" and 10 meant "an extraordinary amount", the average rating of the multidisciplinary team's impact was 7.3, 7.4, and 6.4 in the three semesters when we recorded this data.

Here is how some students described the influence of the diverse environment:

"A lot of ideas were thrown around and it was nice to see how everyone tackled the same problem in different ways."

"The knowledge, and also at times lack-there-of, of my group mates helped to force me to explore more creative solutions, musically. "

"If I had done this with just music majors our project would not have been as creative, I believe. We would have only come from one angle (plus we wouldn't have been able to build it!)"

"Whenever I drew a blank, someone else in my team was able to give an alternative approach to the problem. So many different minds collaborated within one group that it was easy to see outside the box."

4.3 Consensual Assessment

At the end of each semester we used the consensual assessment technique [1] to rate the creativity of the student projects. The non-human conductors were ranked by three categories of observers: the student orchestra that performed while being conducted by the non-human prototype (i.e. the users of these systems), the course instructors, and a multidisciplinary advisory board comprised of faculty members from each discipline who were not involved with the course.

All evaluators agreed that all solutions were very creative in their own ways. However, creativity rankings varied from one evaluator to another based on their area of expertise: engineers appreciated the technical details, while musicians favored systems that conveyed all the information required from a conductor. What is more creative? A non-humanoid robot that is unlike anything we have seen before, or a humanoid robot that performs very close to a human? The first requires new definitions for all the information that is being conveyed to the musicians, an original solution that is not usually appreciated by the orchestra used to human gestures. The second may not seem very original to the outsider, but building a humanoid robot requires creative engineering.

Meanwhile, the course instructors ranked the creativity of the entire process, based on details unknown to outsiders. These included the creativity of solutions to various problems students encountered on the way, and the flexibility of students, some of whom made significant contributions in areas that were not related to their major.

Some of the musicians were tempted to give high rankings to the non-humanoid systems – after all, these were the most original – but most of them ended up favoring usefulness, and ranked the most useful systems (the ones that provided a good amount of correct and easy to understand information) as most creative.

5. CREATIVITY ANALYSIS

Even though our measurements are quantitative (creativity indexes, rankings and self-rankings), it is impossible to devise a quantitative measure for the creativity enhancement that we observed by the end of each semester.

5.1 Individual and Group Creativity

One of the reasons is that our baseline measurements targeted each individual, while the final measure, the creativity ranking of the products, pertains to teams of students. Although the creativity literature documents experiments that demonstrate how collaborative emergence results from the interaction of individuals, the phenomenon is difficult to understand by analyzing the members of the group individually [15].

In our setting students were asked to form teams without any specific input from the instructors. The only requirements were the number of teams, the number of students per team (which varied every semester based on the class makeup), and the fact that each major had to be represented on each team (with a couple of exceptions imposed by low numbers of students from a specific discipline who registered for the class in a particular semester). We encouraged students to "advertise themselves" by listing qualities that they thought would be useful for the project, and they self-selected. Invariably, at the end of the selection process there was one team made up of students who were not picked by other teams. Usually these were the students who were not proactive enough and did not advertise themselves as well as others.

Interestingly, the mean creativity index per team was either the same or higher than the class average, with the exception of the last team whose average creativity index was below the class average. Often this team ended up being ranked lowest by the observers participating in the consensual assessment.

It appears that, probably because of the self-promotion that we encouraged, students gravitated towards students who would compensate for their own knowledge gaps and insecurities.

5.2 Types of Creativity

Our individual measurements also seem inconsistent at first: with the exception of the most and least creative students, the ATTA creativity index does not correlate with self-reported creativity ratings. Such inconsistencies have often been observed in creativity research however, and have been explained through domain specificity. Baer has argued that the skills, aptitudes and motivations that lead to creative performance vary from domain to domain [2]. Similarly, Howard Gardner has proposed a theory of multiple intelligences [5], which he then applied to creativity [6]. He suggested that great creative minds often have relied on different intelligences to manifest their creativity. For example, T.S. Eliot made his reputation through linguistic intelligence, Einstein through logical–mathematical intelligence, while Igor Stravinsky became famous through musical intelligence. Sternberg sees creativity as a set of multiple attributes, which are not mutually exclusive [17]. According to him, people might show consistent individual differences in processes, domains, and styles of creative thinking. Dietrich classifies creativity into deliberate and/or spontaneous modes of processing, each of which can direct computations in cognitive and/or emotional structures [4].

Similar to the creativity types described by Gardner [6], we were able to distinguish at least four different types of creativity as follows:

1. Creativity of design – meeting objectives within constraints, adding additional features to the product that are not necessarily required (i.e., visually pleasing details, etc.).
2. Creativity of problem solving – innovative solutions to a variety of problems that need to be solved before the product can be fully built.
3. Creativity of knowledge acquisition – the various ways in which students looked for information that could help build their product
4. Creativity of self-definition – the flexibility in which students perceived their skill sets, regardless of their major.

5.3 Functional Creativity

The goal of our seminar was to foster functional creativity, which focuses on novel, useful, practical products, as opposed to the traditional aesthetic creativity, which characterizes art [3]. When self-reporting, students thought about creative products they might have built in the past. They were all able to relate creativity to their major, regardless of whether that major was art, science or engineering.

On the other hand, the Torrance test, and its ATTA variant that we administered, looks to measure divergent thinking in the aesthetical realm. This explains why the music majors obtained higher scores than the engineering majors. This is also why we chose not to administer them again at the end of the semester, as we were not expecting an improvement in aesthetic creativity.

Our assessment therefore becomes more qualitative, as we look at the way students self-reported at the beginning and at the end of the semester. As mentioned above, most students found that the environment increased the creativity of their project. And since, according to [8], individual creativity can be characterized by the list of creative products that one builds, students' individual creativity was enhanced through this process.

We have stated, based on student reports, that the multidisciplinary environment that included fundamentally different fields motivated and inspired our students. The class provided an environment with lots of learning opportunities that boosted self-confidence. Some interesting comments from student reflection journals are quoted below:

"It makes you take a step back and forces you to explain things in a way that you're not used to with your fellow engineers. That is one of the major things I enjoy about this class, everyone trying to convey their knowledge to people who might not have any idea about what they are talking about. I think it's a great challenge for all the majors"

"I feel it is good to try to understand a new subject which I previously did not even think about, because it has forced me to learn what feels like a new language... really made me see how different it must be for the mechanical engineers in the class to study the musical aspect, because compared to mechanical engineering theory, music theory has an almost mystic quality."

The motivation and self-confidence that students acquired was reflected in the creativity of their products. Without making it explicit, our students were taught a number of ways in which creativity can occur [16]: conceptual replication (the known is transferred to a new setting), redefinition (the known is seen in a new way), forward incrementation (the known is extended in an existing direction), redirection (the known is extended in a new direction), and reinitiation (thinking begins at a radically different point from the current one and takes off in a new direction).

The team setting compensated for the lack of divergent thinking some students may have had: even if each student provided just one idea, the final result had to be a list of divergent and very creative suggestions.

Our students also learned what experienced scientists, engineers, and even artists already know: functionally creative products don't happen overnight. They are the result of hard work and a lot of brainstorming and experimentation [3]. In their reflection journals, students documented their "aha" moments (i.e. a breakthrough moment when new understanding "fell into place"), along with what conversation, interaction or activity lead them to a different way of looking at or solving an issue with respect to a class. Some examples are listed below.

"It was shocking to hear that all the other students from the "smart" majors (mechanical engineering and computer science) were as confused about conducting and music as I had been about their subject areas."

"Trying to wrap my mind around having my right hand do something and my left hand do something entirely different was surprisingly difficult. It was really trying it (conducting) out for myself that made me realize how much cognitive multitasking this feat required."

"I learned that robots are powered by numbers and not just wheels and motors."

While we saw little breakthroughs everywhere throughout the semester that eventually led to functional conducting systems, no one provided us with an account of a big idea that happened in an unexpected place. Students got to see that although myths like Isaac Newton being hit by an apple in the head are highly unlikely, with hard work creative endeavors are accessible to all of us.

6. CONCLUSION

We presented a framework for fostering creativity in and through computer science. The "Conducting Robots" undergraduate multidisciplinary seminar that we designed and offered not only encourages students to be more creative, but it also effectively teaches strategies that increase creativity.

Through working in multidisciplinary teams that include students majoring in computer science, mechanical engineering, interactive multimedia and music, students are able to build products that are more creative. From the different creativity types that were described in the literature, our approach targets functional creativity, which focuses on useful products, as opposed to the more traditional aesthetic creativity that can be seen in art, and is more relevant to computer science.

Our measures are mostly qualitative. We show that although we collected different quantitative measurements according to multiple strategies from creativity research, these measurements could not be used to quantitatively assess improvement in the creativity of participating students. There are two reasons for this: traditional creativity measures are designed for aesthetic, not functional creativity, and the relationship between individual and group creativity is not yet fully understood.

Our experience can easily be adapted to any multidisciplinary environment. All that is needed is an attractive challenge and a team of diverse backgrounds.

7. ACKNOWLEDGMENTS

This work has been supported in part by National Science Foundation grant #0855973.

8. REFERENCES

[1] Amabile, T., "Social Psychology of Creativity: A consensual Assessment Technique", Journal of Personality and Social Psychology, vol. 43, no. 5, 1982.

[2] Baer, J., "Is creativity domain specific?", in The Cambridge Handbook of Creativity, eds. J. Kaufman, R. Sternberg, Cambridge University Press, 2010, 321-341.

[3] Cropley, D. and Cropley, A. "Functional Creativity. "Products" and the Generation of Effective Novelty", in The Cambridge Handbook of Creativity, eds. J. Kaufman, R. Sternberg, Cambridge University Press, 2010, 301-317.

[4] Dietrich, A., "The cognitive neuroscience of creativity", Psychonomic Bulletin & Review, 11 (6), 2004, pp. 1011-1026.

[5] Gardner, H., "Frames of Mind: The Theory of Multiple Intelligences." Basic Books, New York, 1983.

[6] Gardner, H., "Creating Minds." BasicBooks, New York, 1993.

[7] Higgins, L.F., "Applying principles of creativity management to marketing research efforts in high-technology markets", Industrial Marketing Management, No. 28, 1999, pp. 305-317.

[8] Hocevar, D., "Measurement of Creativity: Review and Critique", Journal of Personality Assessment, Vol. 45, No. 5, 1981, pages 450-464.

[9] "Honda Asimo Robot conducting the Detroit Symphony Orchestra", May 13, 2008, http://world.honda.com/news/2008/c080423ASIMO/, http://www.youtube.com/watch?v=Cf5szwz6Qzc

[10] Newell, A. and Shaw, J.C., "The process of creative thinking", in A. Newell and H.A. Simon (eds), Human Problem Solving, Prentice Hall, Englewood Cliffs, NJ, 1972, pp. 144-174.

[11] Nickerson, R. S., "Enhancing creativity", in Handbook of Creativity, ed. R. J. Sternberg, Cambridge University Press, 1999, 392-430.

[12] Plucker, J. A., Beghetto, R. A., Dow, G. "Why isn't creativity more important to educational psychologists? Potential, pitfalls, and future directions in creativity research" in Educational Psychologist, 39 (2004) 83-96.

[13] Plucker, J. A., and Makel, M. C., "Assessment of creativity", in The Cambridge Handbook of Creativity, eds. J. Kaufman, R. Sternberg, Cambridge University Press, 2010, 48-73.

[14] Salgian, A., Ault, C., Nakra, T. M., Wang, Y., Stone, M. K., "Multidisciplinary Computer Science through Conducting Robots", in SIGCSE '11. Proceedings of the 42nd ACM technical symposium on Computer science education, 2011.

[15] Sawyer, R. K., "Individual and Group Creativity", in The Cambridge Handbook of Creativity, eds. J. Kaufman, R. Sternberg, Cambridge University Press, 2010.

[16] Sternberg, R. J., Kaufman, J. C., Pretz, J. E. The creativity conundrum: A propulsion model of kinds of creative contributions. Psychology Press, New York, 2002.

[17] Sternberg, R. J., "Creativity or creativities?", in Int. J. Human-Computer Studies 63 (2005) 370–382.

[18] Torrance, E. P., "The nature of creativity as manifest in its testing", in R. J. Sternberg (Ed.). The Nature of Creativity, Cambridge University Press, 1988, pp. 43-75.

[19] Ward, T. B., and Kolomyts, Y., "Cognition and creativity", in The Cambridge Handbook of Creativity, eds. J. Kaufman, R. Sternberg, Cambridge University Press, 2010, 93-112.